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INVESTIGATIONS ON LIGHT AND HEAT, MADE AND PUBLISHED WHOLLY OR IN PART WITH APPROPRIATION FROM THE RUMFORD FUND.

XXV.

CONTRIBUTIONS FROM THE PHYSICAL DEPARTMENT OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XIX. — PRINCIPLES INVOLVED IN THE CONSTRUCTION OF PHOTOGRAPHIC EXPOSERS.

By WILLIAM H. PICKERING.

Communicated January 14, 1885.

THERE are many forms of photographic exposers in use, in this country and abroad, and they differ among themselves in many important particulars. The object of this paper is to determine from theoretical considerations the general fundamental principles which should govern their construction, and to suggest what seems to the writer the best practical form of exposer where very rapid action is desired.

(1.) *Position of the Exposer.* — The exposer may be placed either just in front of the plate, or just back of the lens, or between the lenses, or, finally, just in front of the lens. The former position is that generally employed by astronomers for taking photographs of the sun itself. It has the advantage that, by using a very narrow slit, the observer may make the exposure for any one point as short as he pleases; but different parts of the picture will be taken at different instants, so that, if the body is in rapid motion, the final result will be distorted, and not represent the condition of things at any particular instant. Moreover, this would be an inconvenient position for a shutter in an ordinary camera, and the same remark applies to the second place referred to, — just behind the lens. The usual place is in front of the lens. This position has the advantage of convenience, and in general involves less alteration of the lens-tube than if the exposer is placed between the lenses. On the other hand, it has the disadvantages that it exposes one portion of the plate slightly before the other, and that the shutter has a considerably greater distance to travel, so that, if very short exposures are required, this is a serious

objection. If the exposer is of a form opening and closing from the centre, the central portion of the plate will be longer exposed than the rest, thereby producing a "flare spot," as it is called. But if one is to make a specialty of instantaneous pictures, one lens may be devoted to that work, and a lens-tube constructed for the purpose. The attachment of an exposer properly constructed will not interfere with long exposures. If placed between the lenses, the shutter will be nearer the point of support for the camera, and consequently the jar caused by the exposure will be less. All portions of the plate are exposed at the same instant, and for an equal length of time; hence there is no flare spot produced from this cause. From the above it will be seen that the place presenting the most advantages for the shutter is between the lenses.

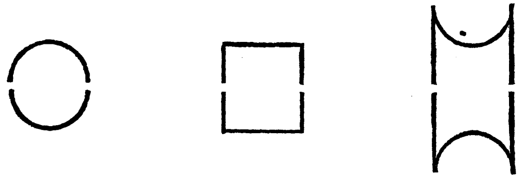
(2.) *Construction of the Exposer.* — The exposure is made either by raising a flap, or by causing a single or double slot to pass by the lens. The object of raising a flap is to expose the top of the picture less than the bottom; but sometimes one does not want to expose the top less than the bottom, and there is no more reason for doing so in instantaneous work than with long exposures. Moreover, there are other contrivances for doing this same thing in other ways, as by holding a board in front of the upper part of the lens, etc. In any case it retards the whole exposure more or less. A flap can never be made to work as quickly as a sliding slot, therefore it cannot be used for very rapid exposures; and, moreover, it cannot be placed between the lenses, so that for the ideal shutter it is ruled out. Sometimes a slot is made to open the lens to its full aperture, to stop, and then return the way that it came. If it comes up from below, and is placed in front of the lens, it will evidently give the foreground a longer exposure than the sky, but it cannot be made to work rapidly, and the jar caused by its reversal comes at just the worst possible time, — in the middle of the exposure. The arrangement, therefore, employing the continuously sliding slot, seems to be the best one.

(3.) *Shape of the Aperture in the Exposer.* — The exposure of any shutter may be divided into three parts: that while the shutter is opening, that while it is opened to its full extent, and that while it is closing. Now any bright moving object will begin to form an image soon after the shutter begins to open, and will continue to form one until it is nearly closed. A dark object, on the other hand, will only produce an image during the exposure by the full aperture. But the exposure must be prolonged until the dark object is fully taken; therefore the opening and closing of the shutter must be as rapid as possible in proportion to

that part of the exposure which is with the full aperture. To insure this result, if a slot is made to pass between the lenses, it should be as long as possible in proportion to the diameter of the aperture. The ends of the slot usually have one of the three following forms. They are either semicircular and concave, rectangular, or semicircular and convex.* Sometimes a single slot is used, and sometimes two, which slide past one another in opposite directions. We thus have six methods of opening and closing the aperture, all in common use. Now it is quite evident that all cannot be right, and perhaps the simplest way of studying them will be by the following diagrams. (See page 486.)

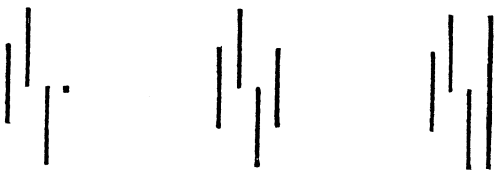
At the top of the page are shown the three terminations. The vertical lines underneath show the distances which the shutter would move while four points of the circular aperture between the lenses are being exposed. The points selected are the centre, *c*, the upper extremity of the vertical diameter, *t*, the lower extremity, *b*, and the end of the horizontal diameter, *s*. The shutters are supposed to fall vertically and uniformly, and the first series represents the case where the central vertical dimension of the aperture in the shutter equals the diameter of the aperture between the lenses. If the circular hole passes the lens, the centre of the aperture between the lenses is exposed, while the shutter moves through the diameter of the hole. The top of the aperture is exposed for the same length of time, but its exposure is half over before that at the centre begins. The exposure at the bottom does not begin until that at the top is over. The exposure at the side is merely for an instant, and therefore does not count for anything. If the hole in the shutter were made somewhat larger than that between the lenses better results would be obtained, and the exposures would resemble more nearly those represented in the second figure, with a square aperture. If the shutter were placed in front of the lens, it will now be seen that the bottom of the plate would be photographed before the top, and that distortion would be thereby produced. By placing it between the lenses, however, no trouble of the sort can occur, as every portion of the aperture exposes all parts of the plate at once. With a square slot all portions of the aperture between the lenses receive an equal exposure. With the third form of slot the sides receive double the exposure of the top, bottom, or centre.

* A diamond-shaped slot is also sometimes used; but this may be considered under the first class.



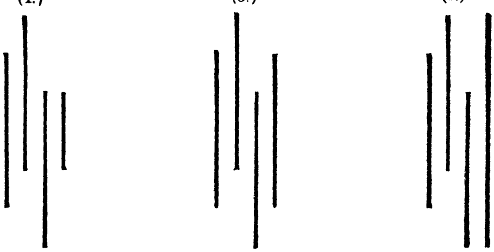
FIRST SERIES.

(1.) *c t b s* (2.) *c t b s* (3.) *c t b s*



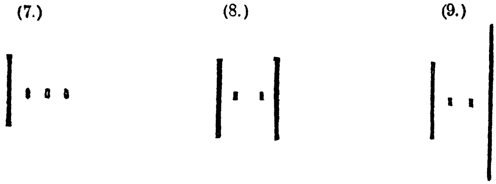
SECOND SERIES.

(4.) (5.) (6.)



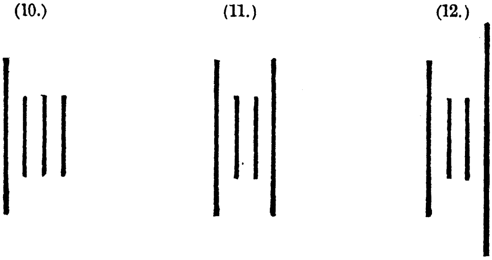
THIRD SERIES.

(7.) (8.) (9.)



FOURTH SERIES.

(10.) (11.) (12.)



In the second series of lines the slots are supposed to be lengthened out by the insertion of a square between the terminations, so that the length down the middle is now twice the breadth. The only change of importance noticed is, that, while before the full aperture was exposed for an instant only, all the time being occupied in opening and closing the shutter, that now the full opening is exposed for an appreciable interval, equal to one third of the total time consumed. By inserting a rectangle longitudinally, instead of the square, still better results would be obtained. In the third series, two slots similar to those used in the first are supposed to slide past one another in opposite directions. If both are circles, as in the first case, the centre of the aperture between the lenses receives the same exposure as it would if there were only one sliding slot, but the top, bottom, and sides receive only instantaneous exposures. The square slots give a better result, and the third form doubles the exposure at the sides. In the fourth series both slots are supposed to be of similar shape to those used in the second set, and here we find two instances where the full aperture is exposed for half the total time of exposure.

Now since all parts of the aperture between the lenses are of practically equal value, it is evident that the best-shaped slot is that one which lets through the maximum amount of light per unit length of total exposure. That will be the slot which gives the best representation of the dark object, with the least motion of the bright one. The following formulæ represent the amounts of light transmitted by each form of aperture. The third column gives the numerical coefficients of r^3, and the fourth the amount of light transmitted for equal times of exposure. The last figure gives the amount of light transmitted per unit length by the theoretically perfect slot, i. e. one of infinite length, moving with infinite velocity. The fifth column gives the percentages of light transmitted by the various apertures, in terms of the theoretically perfect slot. In comparing the amounts of light transmitted by sliding shutters and by hand exposures, the duration of the former must always be multiplied by the figure in this column corresponding to the form of aperture employed.

(1.)	$\frac{16}{3} r^3$	5.33	2.67	.42
(2.)	$2 \pi r^3$	6.28	3.14	.50
(3.)	$(4 \pi - \frac{16}{3}) r^3$	7.24	3.62	.58
(4.)	$(2 \pi + \frac{16}{3}) r^3$	11.61	3.87	.61
(5.)	$4 \pi r^3$	12.56	4.19	.67
(6.)	$(6 \pi - \frac{16}{3}) r^3$	13.52	4.51	.72
(7.)	$\frac{8}{3} r^3$	2.67	2.67	.42
(8.)	$(2 \pi - \frac{8}{3}) r^3$	3.61	3.61	.57
(9.)	$(4 \pi - 8) r^3$	4.57	2.28	.36
(10.)	$(2 \pi + \frac{8}{3}) r^3$	8.95	4.48	.71
(11.)	$(4 \pi - \frac{8}{3}) r^3$	9.90	4.95	.79
(12.)	$(6 \pi - 8) r^3$	10.85	3.62	.58
			6.28	1.00

It will be noted that the exposures Nos. 1, 2, 3, 9, 10, and 11, as shown by the diagrams, last each for two units of time, and may therefore be readily compared with one another. No. 3 lets through the greatest amount of light for any single slot (.58), and No. 11 for a double slot (.79). These are therefore the best forms to use, and if their lengths can be increased in proportion to their breadths so much the better. No. 11 is the better of the two, but presents more mechanical difficulties of construction when high speeds are desired. With No. 8 the exposure is only one half that of No. 11, but its coefficient is somewhat less (.57). This is only a modified form of No. 11, and with No. 7 gives the shortest exposure of any aperture that uncovers the full size of the lens. The ideal practical shutter will then have an aperture of the form No. 3, 8, or 11, as the case may be, and as much lengthened as possible.

(4.) *Motive Power.* — Now as to the driving force to be employed. It has been found that, with a very sensitive plate (Allen and Rowell extra-quick, or the Stanley) and a rapid rectilinear lens, an exposure of $\frac{1}{200}$ sec. was sufficient to make a fair printing negative. The ideal shutter should then give a minimum exposure of not more than $\frac{1}{200}$ of a second and a maximum of perhaps $\frac{1}{2}$ a second. Let us suppose that the aperture between the lenses is one inch in diameter. The slot, if single, must then be capable of moving with a maximum velocity of two inches in $\frac{1}{200}$ of a second. Theoretically this could be obtained by the force of gravity alone only by a fall of sixteen feet. But a shutter of these proportions is evidently out of the question; therefore, for rapid exposures one must resort to springs. These are of three kinds, — india-rubber, metallic coiled, and metallic spiral. The former are convenient and cheap, but cannot be relied upon to give uniform results. Coiled springs, after they are wound up

two or three turns, unwind with a nearly constant velocity, so that, if there is to be much variation in the exposures, (for example, a ratio greater than 1 to 3 or 1 to 4,) we must resort to complicated gearing. For those who are satisfied with these small ratios and comparatively long exposures, as those who are engaged in photographing yachts exclusively, a coiled spring leaves little to be desired, as it is compact and readily carried. On the other hand, if one wishes to vary the exposure through a large range, such as 1 to 100, or to get an exposure of less than $\frac{1}{50}$ of a second, the drop-shutter arrangement offers peculiar advantages.

Such a shutter has been constructed in which the drop is four inches and the diameter of the aperture seven eighths of an inch; but by attaching two two-inch brass spiral springs beneath it, and doubling the velocity by means of a pulley, the speed has been increased from $\frac{1}{20}$ sec. to $\frac{1}{200}$ sec. The tension of the springs may be adjusted, and any intermediate exposure given. A string which is attached to the top of the shutter passes over a pulley, and has a twenty-gram weight fastened to its other end. This exactly balances the shutter when the springs are released, permitting it to remain motionless in any position. This is desirable for focusing, and also for hand exposures. By thus counterbalancing the weight of the shutter, removing the brass springs and pulley, and attaching small weights in their place, the length of the exposure may be increased from $\frac{1}{20}$ sec. to $\frac{1}{2}$ sec. A shutter constructed on these principles has been in use by me now for some months, and works admirably. The exposures under similar circumstances can always he relied on, and never vary among themselves more than ten per cent. Its total weight does not exceed a pound, and it can instantly be adjusted to give any exposure from $\frac{1}{200}$ to $\frac{1}{2}$ second, or to give hand exposures.